LEE, D.H. Great Lakes water levels. In *Michigan's Relative Risk Task Force Report on Hydrology*. Michigan Dept. of Environmental Quality, Office of Special Environmental Projects, Lansing, MI. pp. 8-19 (1997).

The mandate for agricultural water-use reporting ended in 1995. This has left a major gap in water-use information, since agriculture is a major source of consumptive water use, and irrigation sometime conflicts with other water uses. The reporting mandate should be extended and made consistent with ongoing reporting requirements for industrial and thermoelectric power generation. The ability of the DEQ to collect and provide these data to the region depends on the development of a dedicated funding source.

Recommendations

The following four recommendations should be considered in order to help enhance the management of the state's waters:

1. Implementation of a holistic approach to water management with integrated decision-making,

2. Inventory of all county and intercounty drains to minimize potential conflicts over their management,

3. Expansion of Michigan's stream gauging network to reduce risks associated with water-related development, and

4. Identification of current water utilization with the water use registration program including mandated agricultural water use reporting.

GREAT LAKES WATER LEVELS

Of all the Great Lakes states, Michigan's welfare is most intimately linked to that of the Great Lakes and their connecting channels. The state's borders are predominantly defined by the shorelines of Lakes Erie, St. Clair, Huron, Michigan, and Superior, and the Detroit, St. Clair, and St. Marys Rivers. The lakes and rivers are immeasurably important to the state, both economically and environmentally. Our dependence on them makes us vulnerable to fluctuations in their water levels due to natural or anthropogenic effects.

Risks Associated with Fluctuating Great Lakes Water Levels

The adverse consequences of extreme Great Lakes water level fluctuations on public and private interests are well documented (Levels Reference Study Board, 1993). During low water level periods, such as those experienced in the 1920's, 1930's, and 1960's, commercial navigation suffers from loss of adequate navigation depths and reduced cargo capacity, hydropower generation is reduced, water intakes are exposed, and recreational use of the lakes is impaired. During high water level periods, such as those experienced in the 1950's, 1970's, and most recently in 1985 and 1986, riparians suffer property damage due to flooding and increased erosion, metropolitan sewer outfalls are submerged inhibiting discharge, and recreational use of beaches and marinas is impaired. Commercial navigation, which generally benefits from increased cargo capacity during high water periods, also experiences losses due to reduced speeds required to prevent shoreline damage from boat wakes in the connecting channels.

These adverse consequences can be compounded by other factors that affect lake levels. Natural factors are storms, ice jams in the connecting channels, and isostatic rebound of the earth's surface. Storms, with accompanying changes in barometric pressure and high winds, cause lake levels to fluctuate over a small time period (an hour to several days) through wind setup, storm surges, and waves. The magnitude of the short-term fluctuations vary depending on location and shoreline configuration, but can significantly exacerbate flooding and erosion during periods of high lake levels. Ice jams in the connecting channels can occur during the winter and early spring months, resulting in changes in lake levels and localized flooding along the river shores. In addition, isostatic rebound, the gradual rising of the earth's crust from the weight of the glaciers that covered the region during the last ice age, is resulting in a gradual increase in lake levels along the southern and western shores, and a corresponding decrease along the northern and eastern shores of the Great Lakes. For example, water levels at Marquette, Michigan are now 0.11 meters higher relative to the shoreline than at the beginning of the century for the same mean lake level (Lee and Southam, 1994). The effects of isostatic rebound have long-term implications for lake level management, municipal flood protection and drainage/sewer system design, and harbor maintenance.

Anthropogenic factors compounding adverse consequences due to Great Lakes fluctuating water levels include lake regulation, diversions and consumptive uses, connecting channel encroachment or excavation, urbanization and other land use changes, and the potential for a changed climate. Table 3 shows the estimated impact of some of the modifications to the natural system made to date.

Table 3. Estimated impact of modifications to the natural Great Lakes system (meters) (IJC, 1989).

LAKE	IMPACTS OF CHANNEL DREDGING/FILLING		IMPACT OF CURRENT DIVERSIONS			IMPACT OF REGULATIONS		ACCUMU-LATED IMPACTS
	MICHIGAN & HURON	ERIE	LONG LAC & OGOKI	CHICAGO	WELLAND	SUPERIOR	ONTARIO	
SUPERIOR (1)	0	0	0.09	0	0	0.17	0	0.26
MICHIGAN/ HURON	-0.38	0.04	0.11	-0.06	-0.04	0	0	-0.33
ERIE	0	0.12	0.07	-0.04	-0.12	0	0	0.03
ONTARIO	0	0	0.07	-0.04	0	0	-0.09	-0.06

1. Impacts of Lake Superior Regulation are taken from Quinn (1978).

Data, Information, and Analyses Needed to Reduce Risks Due to Great Lakes Water Level Fluctuations

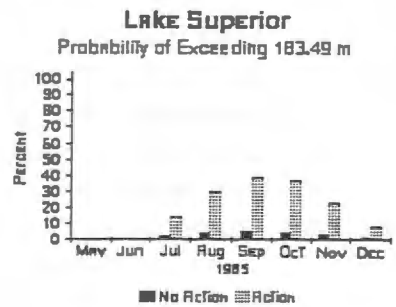
Improving Water Level Forecasts and Quantification of Risk. Although much is known about the physical processes that affect Great Lakes water levels, the greatest risk arises from an inability to predict the magnitude and timing of annual and seasonal fluctuations, with satisfactory accuracy, more than one month into the future. Presently, water level forecasts are made one to six months into the future. Recent analyses of state-of-the-art Great Lakes water level forecasts have shown that these forecasts are only marginally better than using long-term average changes in lake levels superimposed on beginning-of-month water levels (Croley and Lee, 1993; Lee, 1992). Furthermore, the forecast accuracy cannot be significantly increased without improvements in long-range (30 days or more into the future) weather forecasting. The water level forecasts currently available to the public provide a deterministic "most probable" forecast and/or a range of expected levels (USACE, 1994; Canadian Hydrographic Service, 1994). Probabilities of exceedance or non-exceedance are not explicitly given.

During periods of extreme water levels, governments (local, state, and federal) and commercial and private interests are faced with making decisions regarding what actions, if any, they should take to avoid or mitigate damages and losses. They must weigh the risks of taking action versus no action. They must also decide when to take action. Because many measures take time to implement (i.e., construction of shore protection) or to become effective (i.e., deviations from lake regulation plans), decisions must be made well in advance of reaching critical water levels. These decisions must be made with little certainty of future water levels. Thus, in addition to our inability to predict levels, we are unable to quantify the risks involved in our decisions with the forecasts currently disseminated.

How then, can people affected by fluctuating Great Lakes water levels make decisions that depend on knowledge of future water levels? In addition, how do they measure the risks associated with their decision? As suggested by Croley and Lee (1993), the answer lies in the use of probabilistic forecasts. A probabilistic forecast gives the decision-maker a range of outcomes with their associated probability of occurrence.

Lee, Clites and Keillor (1997) have developed a simple technique for producing probabilistic water level forecasts and have demonstrated its application to several case studies of decision-making during periods of extreme water levels. One case study, particularly relevant to Michigan, examined the 1985 International Joint Commission (IJC) decision to store water in Lake Superior to reduce high levels on Lakes Michigan-Huron, Lake St. Clair, and Lake Erie. However, the decision to store water on Lake Superior exacerbated high water conditions on that lake, and its water level exceeded the upper regulation limit in October and November. The risk of this occurrence was not quantified a priori. Lee, Clites and Keillor (1997) retrospectively generated probabilistic forecasts for Lake Superior and Lakes Michigan-Huron and used them to quantify the risks of exceeding Lake Superior's upper regulation limit (183.49 m) and

Lakes Michigan-Huron's previous record water level (177.10 m). Figure 1 summarizes the risks for May through December, 1985, based on the probabilistic forecasts for each lake. From this figure, it can be seen that by reducing Lake Superior outflows, the probability of Lakes Michigan-Huron exceeding 177.10 meters decreased, especially for June through October. The monthly exceedance probabilities were reduced for these months from a range of 12 to 59 percent to two to 34 percent.



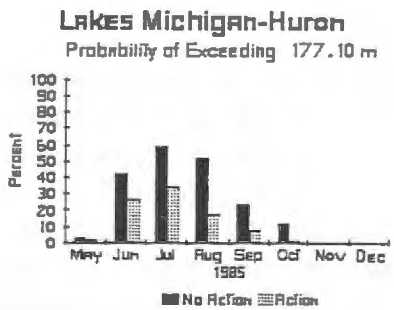


Figure 1. Change in risk of Lake Superior and Lakes Michigan-Huron exceeding upper water level limits with and without reductions in Lake Superior outflows Great Lakes seasonal water level fluctuations

However, the risk of Lake Superior exceeding its upper regulation limit of 183.49 meters was correspondingly increased, significantly for July through December. For these months, the probability of exceeding 183.49 meters increased from a range of two to six percent to nine to 40 percent. With the reduction in outflows, the risk of Lake Superior exceeding its upper regulation limit became greater than the risk of Lakes Michigan-Huron exceeding its previous record level for August through December.

With the risks of the action quantified, the decision to take action becomes a policy decision. Should a particular group's risk be increased to decrease the risk of another group? Can the risks be related to potential gains or losses by users of the lakes (e.g., Michigan citizens)? To do this, reliable estimates of damages due to fluctuating water levels must be developed. Such estimates can be combined with the probabilistic forecasts to quantify the risks associated with lake management decisions and mitigative actions.

Until the skill of state-of-the-art water level forecasts significantly improves (and this depends on improved long-range weather forecasts), probabilistic water level forecasts should be used by state resource managers for anticipation of and preparation for crisis conditions, and for quantifying risks (costs) associated with mitigative actions. In addition, Michigan should develop reliable estimates of damages due to fluctuating lake levels for use with the probabilistic forecasts in assessing risks. Probabilistic forecasts should be requested as a special product from the U.S. Army Corps of Engineers (USACE), who now have the primary authority for issuing lake level forecasts.

Improving Identification and Management of Flood Hazard Areas. Flooding along the Great Lakes shoreline and connecting channels is one of the consequences of fluctuating seasonal and annual water levels, compounded by storm-induced water level fluctuations (storm surges, seiches, and wave runup) or ice jamming. Flood hazard areas for the Great Lakes shoreline of Michigan have been partially identified by the Federal Emergency Management Agency's (FEMA) National Flood Insurance Program. A report prepared by the USACE (1988) under contract to FEMA, *"Revised Report on Great Lakes Open-Coast Flood Levels,"* provides 100-year flood levels for reaches of the Great Lakes open-coast and connecting channels (neglecting flooding due to ice jams). Flood levels are not defined for shorelines protected by the presence of islands, or bays subject to additional wind setup. Major areas of Michigan's coastline for which flood levels are not given in the report are summarized in Table 4. However, several special studies have been done to determine flood levels for many of these areas, including Little and Grand Traverse Bays, and Saginaw Bay.

Maps of flood hazard areas are available from Michigan for those communities which participate in the National Flood Insurance Program. The state maintains a list of participating communities. However, not all flood hazard areas are mapped, and some mapped areas have not been revised in accordance with the new flood levels of the *Revised Report on Great Lakes Open-Coast Flood Levels*. The flood levels of the revised report take into account the record water levels of 1985 and 1986. Differences in flood levels between the earlier 1978 report and the revised report differ by as much as 0.37 meters, with the largest differences occurring on Lake Michigan, Lake St. Clair, and Lake Erie. Map revisions could be substantial. In addition, those reaches along the connecting channels prone to flooding due to ice jams should be mapped.

In the recently completed IJC *Levels Reference Study ...*, an analysis of land use by the Land Use and Shoreline Management Task Group found that the general trend in the basin over the last several decades has been an increase in shoreline development, primarily for residential use at the expense of natural areas and agricultural land. Examinations of future trends found that this increase in development will continue (Working Committee 2, 1993). This trend, along with unmapped or outdated maps of hazard areas, has the potential for development within flood zones and future flood damages.

Michigan should ensure that all shoreline flood hazard areas are identified, adequately mapped or revised, and policies implemented for the management and development of these areas. The Land Use and Shoreline Management Task Group found the following measures to be effective where already implemented in the Great Lakes - St. Lawrence River Basin:

1. Setback and flood-proofing requirements in undeveloped areas,

2. Setback and flood-proofing requirements in developed areas when lots are redeveloped and in combination with other measures such as dwelling relocation,

3. Acquisition or relocation of properties and structures where justifiable due to significant infrastructure at risk, or where shoreline areas exhibit unique shoreline characteristics or habitat, and

4. Properly designed shore protection that considers potential negative impacts on adjacent and downdrift property.

These shoreline management alternatives must be evaluated and undertaken considering unique site specific conditions.

Preventing Connecting Channel Encroachment. As previously shown in Table 3, past dredging and infilling activities in the St. Clair and Detroit Rivers have had significant impact on lake levels. In recent years, there have been many new proposals along the St. Clair and Detroit Rivers involving fills or other channel modifications. A number of these proposals are related to fisheries habitat and wetland enhancement or creation as part of the St. Clair and Detroit River Remedial Action Plans. At the same time, there have been other development proposals ranging from municipal park development (involving shore hardening and infilling), in-river dredge disposal sites, and marina developments. In nearly all cases the proponents have argued that the hydraulic effects would be small, however, in the long-term, many fills and channel alterations will have an accumulative effect with significant impacts on lake levels, and flows, ice and sediment transport through the rivers (Brown, 1995).

A joint U.S. and Canadian project has been proposed (Brown, 1995) to perform a holistic assessment of the potential impacts of habitat enhancement and development along the entire course of the St. Clair and Detroit Rivers. The assessment would involve federal, provincial/state, and local jurisdictions. The Michigan Department of Natural Resources (DNR) has participated in preliminary meetings of the proposed joint project. Michigan should continue its involvement and lend full support to the project, and assist in implementing findings and recommendations.

Table 4. Portions of Michigan's shoreline for which 100-year flood levels are not specified in the *Revised Report on Open-Coast Flood Levels* (USACE, 1988).

LAKE	SHORELINE REGION	LAKE	SHORELINE REGION
Superior	Whitefish Bay	Huron	Saginaw Bay[1]
	Grand Island		Thunder Bay
	Huron Bay		Straits of Mackinac
	Keweenaw Bay		LesCheneaux Islands
	Chequamegon Bay		Drummond Island
	Apostle Island		St. Joseph Island
Michigan	Little Traverse Bay[1]	Erie	Maumee Bay
	Grand Traverse Bay[1]		
	Straits of Mackinac		

1. Special studies have been performed to determine the flood levels of these areas.

Improving Accounting of Consumptive Water Uses. Present consumptive use of Great Lakes waters is a small, but essential part of the water balance. Currently, consumptive use basin-wide (U.S. and Canada) is estimated to be of the same order as the Chicago Diversion, about 85 cubic meters/second (3,000 cfs) (Great Lakes Commission, 1992). Estimates of consumptive use are required to determine their impact on Great Lakes levels and flows, and on which to base projections of future consumption. In 1987, the Great Lakes Regional Water Use Database Repository was established to collect and store U.S. and Canadian water use information, and is maintained by the Great Lakes Commission.

Of the Great Lakes states, Michigan is the largest withdrawer of Great Lakes waters (VanTil, 1995), but has only recently passed legislation requiring the reporting of water withdrawals by major use categories (thermo-electric power generation, public water supply, irrigation, and industrial). The state has established a Water Use Information System, under the jurisdiction of the DNR, which was funded by a three-year grant. The grant expired at the end of the fiscal year 1996. The activity was continued under a water user fee basis until December 1999. Consequently, there is a need to explore other funding sources. The development of the Water Use Information System has made significant strides in establishing baseline estimates of Michigan withdrawals and consumptive uses. However, to continue its development, including projections of future uses, adequate funding of the Water Use Information System, equal to that of other Great Lakes states' funding levels, must be provided.

Implementing the Recommendations of the Levels Reference Study Board. As a result of the heavy damage and widespread public concern that resulted from the record high Great Lakes water levels of 1985 and 1986, the Canadian and U.S. governments requested on August 1, 1986, that the IJC examine methods that could alleviate the problems associated with fluctuating water levels. After several years of intense study and public involvement, the Levels Reference Study Board (1993) presented its final report to the IJC. Forty-two recommendations for actions on water level issues were made. Many of these recommendations require participation or action at the state level. Michigan should review these recommendations and act upon them where possible. Of the 42 recommendations, the following are perhaps the most relevant to the Michigan (Levels Reference Study Board, 1993): Recommendation one concerning the adoption of Guiding Principles; Recommendations 11 - 17 concerning land use and shoreline management; Recommendations 18, 22 - 23 concerning emergency preparedness; Recommendation 24 concerning expansion of the Lake Superior Board of Control membership to include representation from citizens, states and provinces; and Recommendations 31 - 36, 38 - 42 concerning management and operational improvements including meteorological observations, hydraulic and hydrologic modeling, coordination of hazard mapping, flood damage surveys, and climate change impacts.

Preparing for a Changing Climate - the "Greenhouse" Effect. Many people greet this topic with skepticism, confusion, or indifference. The scientific uncertainty surrounding climate change due to the "greenhouse" effect and the inability of an individual to observe climate change, make it difficult for the average person to synthesize the available information and relate it in a meaningful way to his or her daily life. However, according to Mahlman, 1991, "global warming is a real and fundamentally sound issue." Scientists are certain that emissions resulting from human activities are substantially impacting the atmospheric concentrations of the greenhouse gases: carbon dioxide, methane, chlorofluorocarbons, and nitrous oxide. Since the industrial revolution, the combustion of fossil fuels and deforestation have led to an increase of 26 percent in carbon dioxide concentration in the atmosphere. Scientists are also certain that these increases will enhance the natural greenhouse effect, resulting on average in an additional warming of the Earth's surface. With a scenario that assumes little or no action is taken to reduce greenhouse gas emissions, the Intergovernmental Panel on Climate Change (IPCC) has predicted that the global mean temperature will increase about 0.3 degrees centigrade per decade over the next century, resulting in a one degree centigrade increase above the present value by 2025, and three degrees centigrade before the end of the next century. Reductions in emissions from human activities of greenhouse gases of over 60 percent would be required to stabilize their concentrations at today's levels (IPCC, 1990).

The IPCC includes the caveat that there are many uncertainties in their predictions with regard to the timing, magnitude and regional patterns of climate change, due to incomplete understanding of sources and sinks of greenhouse gases, clouds, oceans, and polar ice sheets, and their complex interactions. It does not rule out that surprises may occur as scientific understanding increases and modeling capabilities improve. However, these uncertainties should not prevent us from using today's "best guesses" in further pursuing our understanding of the possible impacts of climate change. As Mahlman (1991) stated, *"the issue is not 'Should we respond?' but rather 'What are appropriate kinds of responses in the next decade given the scientific uncertainties, the large confusion on the impacts side, and the potentially high social cost of responding?'"*

The effect of doubling of "greenhouse" gases on Great Lakes hydrology was initially explored by the Great Lakes Environmental Research Laboratory at the request of the

USEPA (1989), and more recently, as part of the IJC's *Levels Reference Study ...* report (Task Group 2, 1993). As discussed in Croley (1991), water supplies to the Great Lakes under a changed climate were developed based upon simulations from various general circulation models (GCMs). Lake levels were obtained by routing the net basin supplies derived from the climate change scenarios through a Great Lakes regulation and routing model until steady-state conditions were obtained. The relative differences in the average annual steady-state levels under the changed climate from the present conditions are summarized in Table 5.

The changes in lake levels reflect the profound impacts that could occur to Great Lakes basin hydrology as a result of climate change. Higher air temperatures under the climate change scenarios would lead to higher over-land evapotranspiration and lower runoff to the lakes. Earlier runoff peaks would occur since snowpack is reduced and the snow season is shortened. This would result in a reduction in available soil moisture. Water surface temperatures would peak earlier and would be higher with larger amounts of heat resident in the deep lakes throughout the year. Buoyancy-driven turnovers of the water column would not occur as often on all lakes except St. Clair. Currently, they occur twice a year on all lakes. Ice formation would be greatly reduced over winter on the deep Great Lakes, and lake evaporation would increase. The average steady-state net basin supplies to all lakes would be greatly reduced (20% - 100% under the Canadian Climate Center scenario) (Croley, 1991). These impacts would require significant adaptation and would affect every aspect of human health and the state's environment and socioeconomic institutions.

Table 5. Relative differences in average annual lake levels under a changed climate, as predicted with data from various GCMs (meters).

LAKE	GISS[1]	GFDL[2]	OSU[3]	CCC[4]
Lake Superior	- 0.46	-	- 0.47	- 0.30
Lakes Michigan-Huron	- 1.31	- 2.48	- 0.99	- 1.76
Lake St. Clair	- 1.21	- 2.12	- 0.87	- 1.60
Lake Erie	- 1.16	- 1.91	- 0.79	- 1.49
Lake Ontario[5]				- 1.40

[1] Results based on GCM output from Goddard Institute for Space Studies (Hartmann, 1990)
[2] Results based on Geophysical Fluid Dynamics Laboratory (Hartmann, 1990)
[3] Results based on Oregon State University (Hartmann, 1990)
[4] Results based on Canadian Climate Center (Lee and Quinn, 1992)
- Levels were not computed due to failure of the regulation plans with these scenarios.

Changnon (1995) recently provided a review of states' involvement to date in the global climate change issue. Of the 50 U.S. states, 22 have taken some action on the climate change issue. Michigan was not listed among the 22 states identified. Although Michigan has not developed a policy which is specifically targeted at global warming issues, it has, however, continued to reduce emissions through several other policy initiatives (Harrison, 1997). According to Changnon (1995), the 22 states have primarily acted upon two basic policies put forth by the 1989 National Governors' Association Task Force on Global Climate Changes (NGA, 1990):

1. Mitigation of potential climate change through control of greenhouse gas emissions, primarily through energy policies, and

2. Use of states' influence over emissions through their utility, land-use, transportation, taxation, and other authorities.

Additionally, nine of the 22 states have encouraged and/or organized in-state research focusing on climate change.

Changnon (1995) also presents the Illinois' response in detail, which is broader in scope than that of other states, and goes beyond mitigation alone. He reports that Illinois has tried to address other questions including the scientific certainty of climate change; the potential impacts of climate change on Illinois; adaptation and mitigation to deal with the change; and the influence of Illinois policies on federal policies. Illinois' actions included the establishment of the Global Climate Change Office at the Illinois State Water Survey. The Office developed plans to foster research on the physical, socioeconomic, and policy aspects of climate change in Illinois; to encourage new methods and systems for measuring climate change and its effects on the hydrologic cycle of Illinois; and to provide information on climate change to the general public, scientific university/college staff and students, and state policy makers. The Governor of Illinois also established an Illinois Task Force on Global Climate Change that ultimately identified five major issues relating to state policy, and made significant recommendations that could be enacted now through existing state agencies. The Illinois General Assembly also established a permanent climate change task force to provide continuing policy guidance.

Changnon (1995) presents arguments as to why states can no longer afford to ignore the climate change issue:

1. Federal program interest in and support of state and regional impacts and adaptation research is inadequate,

2. Although scientific uncertainties still exist, it is clear that national and international policies are being developed and state policy is emerging in its formative stages,

3. There is a growing national and state realization that states must play a pivotal role in the development of local and state programs and regulations relating to the issue, and

4. States need to assess the policy aspects of the issue if they are to have an organized voice in the ongoing national policy debate on the issue.

Michigan should begin to consider the potential impacts of climate change, and formulate policies for adaptation, mitigation, and further research. Michigan could use Illinois' approach as a model for the development of a more focused program to address the issue of climate change.

Recommendations

This following addresses some of the data, information, and analyses needed to reduce risks due to Great Lakes water level fluctuations. Many other needs exist, but may be more appropriately addressed at the federal level than at the state level. In summary, the major recommendations are:

1. Until the skill of state-of-the-art water level forecasts significantly improves (and this depends on improved long-range weather forecasts), probabilistic water level forecasts should be used by state resource managers for anticipation of and preparation for crisis conditions, and for quantifying risks associated with mitigative actions. In addition, Michigan should develop reliable estimates of damages due to fluctuating lake levels for use with the probabilistic forecasts in assessing risks. This type of forecast should be requested as a special product from the USACE, who now have the primary authority for issuing lake level forecasts,

2. Michigan should ensure that all Great Lakes shoreline flood hazard areas are identified, adequately mapped (new or revised), and policies implemented for their management and development,

3. Michigan should continue its involvement and lend full support to the binational project to assess and prevent encroachment upon the St. Clair and Detroit River channels, and assist in implementing findings and recommendations,

4. To obtain accurate accounting of Michigan water withdrawals and consumptive use of Great Lakes water, including projections of future uses, adequate funding of the Water Use Information System, comparable with that of other Great Lakes states' funding levels, must be provided,

5. Michigan should review the recommendations of the IJC's Levels Reference Study Board (1993) and act upon them where possible, and

6. Michigan should look at the potential impacts of climate change more closely, and specifically formulate policies for adaptation, mitigation, and further research. Michigan could use the approach

adopted by Illinois as a model for the development of a more focused program to address the concerns of possible climate change.

GROUND WATER

Ground Water Use is Increasing

Ground water residing in aquifers below the surface of the earth is one of Michigan's most valuable natural resources. It is the source of water for 43 percent of Michigan's population and nearly all households not supplied by public systems (Bedell, 1982). The principal aquifers in Michigan are in glacial deposits and sedimentary bedrock. Aquifers that produce sufficient water for domestic supplies are present in nearly all parts of the state. The four largest metropolitan areas supplied by ground water are Lansing, Kalamazoo, Battle Creek, and Jackson. Lansing uses water from the Saginaw aquifer, Kalamazoo from aquifers in glacial deposits, Battle Creek from the Marshall aquifer, and Jackson from both the Saginaw and Marshall aquifers. Ground water is also the source of 38 percent of the total water used for irrigation (Bedell and VanTil, 1979) and, thus, is critical to agricultural development in Michigan.

Withdrawal of ground water is expected to rise in the coming century as the population increases and available sites for surface-water reservoirs become more limited. For example, a study done for the Ground Water Management Board in the Lansing Metropolitan Area indicates that average ground water pumping will increase from 44 to 57 million gallons/day between 1995 and 2020. Increased demand, reduced ground water quality, and inability to find sufficient supplies of ground water have caused some municipalities to withdraw water from the Great Lakes for supply if the community is close enough to the lakes to make a connection cost effective.

Ground water plays another important, but less known, role in the hydrologic cycle. It contributes water to streams, lakes, and wetlands during periods of low surface runoff. This baseflow is the reason that streams continue to flow during periods of low rainfall or snowmelt. By maintaining a relatively consistent baseflow to surface water, the ground water flow system helps streams support wildlife and an aquatic habitat that is essential for a healthy environment.

We only Pump a Fraction of the Ground Water Available

To help define the ground water flow system, it is useful to estimate an average regional water budget. This hydrologic budget balances precipitation with the sum of evapotranspiration, overland flow to streams, and baseflow of streams.

Precipitation averages about 32 inches/year in the Lower Peninsula of Michigan and ranges from 28 to 40 inches/year. Total stream runoff averages about 12 inches/year and ranges from eight to 16 inches/year. Baseflow averages eight inches/year, which is approximately the amount of water recharged to the ground water system on a long-

Michigan's Relative Risk Task Force Report on Hydrology
(Draft Report)

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Surface and Ground Water Hydrology Alteration Task Force
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October 1997

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